

XML-Based Formulation of Field Theoretical Models [†]

*A Proposal for a Future Standard and Data Base for Model Storage,
Exchange and Cross-checking of Results [‡]*

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Abstract

We propose an XML-based standard for formulation of field theoretical models. The goal of creation of such a standard is to provide a way for an unambiguous exchange and cross-checking of results of computer calculations in high energy physics. At the moment, the suggested standard implies that models under consideration are of the SM or MSSM type (i.e., they are just SM or MSSM, their submodels, smooth modifications or straightforward generalizations).

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1 Introduction

The progress of high energy experimental physics and the general interest in analysis of the Standard Model (SM) as well as its various modifications require the accurate theoretical computations of process characteristics to compare experimental results with theoretical predictions. The basic tool for this is the Feynman diagrammatic technique of computing matrix elements and, consequently, all physics quantities in high energy physics (HEP). However, as the number of final state particles grows (due to grow of the beam energy of particle accelerators) the number of relevant Feynman diagrams becomes huge. The same is true for various generalizations of the Standard Model (even for relatively small number of final state particles), in particular, in the case of the Minimal Supersymmetric Standard Model (MSSM) because of large number of intermediate propagators. Therefore computation of all but the most simple processes is a quite lengthy task, prone to errors and mistakes. This means that Feynman amplitude calculation becomes impossible for practically interesting processes when one calculates cross sections by hands.

Fortunately, the real power of the Feynman approach lies, through the use of definite rules, on *straightforward* transformation of each diagram in an algebraic expression representing its quantitative contribution to the process. Thus the perturbative calculation in quantum field theory can be realized as an *automatic computation system*. There appeared several such systems, for instance, *CompHEP* [1], *Grace* [2], *MadGraph* [3], *VecBos* [4], *WbbGen* [5], and both theorists and experimentalists can benefit from these powerful packages for speeding up time consuming calculations. Another set of packages, such as *Herwig* [6], *Isajet* [7], *Pythia* [8] were developed for preparing event generations.

A typical *fully* automatic computing system for matrix element calculation has the following main modules:

- model definition;
- process definition;
- graph generation, drawing and selection;
- matrix element elaboration;
- analysis of kinematics and phase space integration;
- calculation of cross section;
- event generation.

An important condition for a successful use of automatic computation system in general, for cross-checking and verification of results obtained with the help of different packages as well as for a correct extraction of physical information is an unambiguous and transparent representation of the input data. The main goal of the present work is to develop and implement a more or less universal **Standard for Model Formulations** (SMF) in order to provide:

- an easy and unambiguous exchange through Internet by different QFT models between groups carrying out automatic computer calculations in high energy physics;

- a possibility for creation of interfaces automatically transforming a model presented in the standard into inputs for different automatic computing systems.

Our proposal is currently dealing only with the first stage of automatic calculations, namely, with a *model definition*. In the future, the standard should be extended to the second stage, i.e., *process definition*, as well.

Notice that at first sight it seems enough to fix the Lagrangian of a quantum field theoretical (QFT) model to define it completely - at least, at the perturbation theory level (in general, one should, in addition, fix boundary conditions). However, in the case of real computer calculations, the numerical results may, in general, depend on choice of a set of constants (e.g., coupling constants, masses, etc.) which are considered as a basic one (the obvious necessary condition for such a set of constants is that all other constants entering the model can be expressed through the basic ones), see, e.g. [9] and refs. therein. Another potential source of possible differences in results obtained for models with identical Lagrangians is different ways of representations of mathematical transcendental numbers like $\sqrt{2}$, π , etc. Therefore, the standard should include, in addition to Lagrangians, information about these peculiarities.

One more important requirement to the practical standard is an easy perception and understanding of a model. For this aim it should include elements of classification of models (e.g., submodel of SM, beyond MSSM, etc.), general description of the model, lists of fields and corresponding particles (in general, they are not in one-to-one correspondence: some fields can be auxiliary and do not produce any particles). Thus from purely theoretical point of view, the standard contains exceeding information which, however, proves to be important for practical purposes.

2 The Language for Representation of the Standard for Model Formulations

For a successful development of the standard for model definition an appropriate method of representation and underling language must be chosen. To achieve the goals, the chosen language has to

1. be suitable and flexible enough for an adequate storage and representation of all the details needed for (perturbative) analysis of QFT models;
2. be platform independent and allow an easy computer processing of the model input data (set of fields, particles, their quantum numbers, vertices, etc.), in particular, a creation of an interface between the formulation of QFT models in this standard and computer programs for matrix element calculations or event generations;
3. provide an easy exchange of the data through computer nets, in particular, through the Internet;
4. provide storage of the information about models *separately* from its visual representation: this essentially simplifies computer data processing, creation of the interface

and allow an easy modification of the visual representation by users depending on their specific aims and tastes.

In our opinion, the best candidate for such a language is the **XML** (Extensible Markup Language) which satisfies all the above requirements. The attractive features of XML which make it suitable for the development of SMF are the following (for an introduction to XML, see, e.g., [10, 11]):

- XML has been designed to allow every meaningful division of a document to be unambiguously identified as part of a coherent tree structure that either a human or a computer can use. Thus, XML provides an application-independent format in which data can be shared.
- To achieve such an application-independence, this is for disparate groups may agree to build and use for their applications a defined Document Type Definition (DTD). The latter defines the structure of the documents. Groups employing the same DTD then know that they can use data from applications created by any other groups. Moreover, there is the potential for exchange of data between parties without significant prior agreement (e.g., through WWW): a DTD sent with the XML data can provide the recipient with all the information they need to interpret and use it.
- The nature of XML data is not dependent on specific features of the platform on which it is used. Hence, if one upgrades and extends a system or application XML data can be still interpreted without requiring additions to the system foundations (like emulators). Especially this is important if one makes data or information publicly or widely accessible to others.
- An essential advantage of XML is an existence of public libraries of parsers for XML-files suitable for development of various application program interfaces (API).
- XML is, in fact, a meta-language, a special language that allow one to completely describe a class of other languages, which in turn describe documents. Each of the latter languages are designed for every specific purpose to reach it in the most effective way.
Example: XML-based language MathML[12] aimed at representation and transmission of mathematical expressions through the Internet.
- With the help of special tools (Cascading Style Sheets (CSS), Extensible Stylesheet Language (XSL), etc) the information stored in XML-language can be represented in a visual form using the *standard Internet browsers* (such as Internet Explorer, Mozilla, Amaya, coming version of Netscape) similarly to the usual HTML-pages.

3 The Scope of the Standardization

One may aim at different levels of systematization of QFT models and the corresponding standardization of their formulation.

Thanks to its generality and conciseness, the Feynman diagram method has spread, besides high energy physics, over many other research fields dealing with many-body systems like atomic, nuclear and solid state physics. Therefore, at the most general level it would be desirable to describe an arbitrary QFT model. In this case, models have to be appropriately classified, in particular, according to the following general characteristics:

- dimensionality of the space-time in which the model is formulated (low dimensional models are interesting for testing new theoretical ideas and in the solid-body physics while higher dimensional models are nowadays seriously considered as promising candidates for solution of some long-standing problems in high energy physics);
- existence or absence of gauge invariance;
- existence of supersymmetry (including separation into component (on-shell) and superspace (off-shell) SUSY-formulations), *etc.*

Because of their generality this level requires, as a *starting* point, use of the corresponding Lagrangians in their *explicit form*. Then, using the information stored with the help of XML and MathML, a special computer program should produce the corresponding Feynman rules, also presented in the XML-format. At the moment, a realization of this project is in its very beginning.

As a first step, it is reasonable to develop the standard only for SM- or MSSM-like gauge models including their submodels (QED, QCD, *etc.*) as well as their closest modifications and generalizations. Moreover, in the present work we restrict ourselves to a simple example of the modified electrodynamics, namely the QED with additional four-fermion interactions described with the help of an auxiliary non-dynamical neutral field (that is the low-energy approximation for the interactions mediated by the Z-bosons).

4 General Structure of the Standard

The Standard starts from an acronym for the chosen model following by an indication of a type of the model (e.g., subset of modified SM; beyond MSSM; modified MSSM, *etc.*). Further information about a QFT model in the proposed standard is separated into ten parts:

1. **General properties.** This part contains the following general characteristics of models:
 - gauge group;
 - existence of supersymmetry and number of SUSY generators;
 - information about interactions and the corresponding quantum numbers in the model under consideration;
 - existence or absence of Higgs particles;
 - general features of the matter sector (e.g., number of generations);
 - type of chosen gauge conditions.

2. **Fields entering the model.** The second part contains information about quantum fields in the model: their physical meaning, properties under the Lorentz transformations, reality or complexity and chosen symbolic notation for them.
3. **Particles entering the model.** This part presents the corresponding particles together with their characteristics (mass, spin, etc.).
4. **Basic physical constants.** Here the basic set of *independent* physical constants entering the model is fixed. In general, this set can be chosen in different ways and, in principle, the different sets may lead to apparent discrepancies in results for the same theoretical model.
5. **Dependent (auxiliary) physical constants.** This part contains a list of important physical constants which can be expressed through the basic ones.
6. **Way of computer representation of mathematical constants.** Here a way for computer representation of transcendental mathematical constants (like, e.g., π , $\sqrt{2}$, etc.) is defined (it can be symbolic or numerical representation; in the latter case, the chosen precision of the representation should be indicated).
7. **Free Lagrangian density.** This is the explicit expression (the corresponding part of the source file is written with the help of MathML) of the free part of the Lagrangian for the model under consideration.
8. **Gauge conditions (explicit expressions).** This part fixes gauge conditions. The gauge fields corresponding to different subgroups of the total gauge group may satisfy to different gauge conditions. Therefore, the part contains the list of the subgroups and the corresponding conditions.
9. **Propagators.** The free Lagrangian together with the gauge conditions define propagators for the fields. Thus, strictly speaking, the information (an explicit form of the propagators) containing in this part is exceeding. But it proves to be convenient for practical purposes because propagators directly enter the Feynman rules and expressions corresponding to Feynman diagrams. On the other hand, a derivation of propagators from the Lagrangian and gauge conditions requires more or less lengthy and accurate calculations. Thus their explicit presentation makes easier a comparison of input data.
10. **Interaction Lagrangian and vertices.** This part contains terms in the interaction Lagrangian of the model and the corresponding factors in matrix elements (according to the Feynman rules).

In the next section we describe a relatively simple example of a QFT model presented in the framework of the proposed Standard (XML-SMF).

5 A Simple Example of XML-SMF

As an example of XML-SMF we shall consider Quantum Electrodynamics (QED) with additional four-fermion interactions, the latter being described with the help of an auxiliary Z -boson field with non-dynamical propagator.

According to the steps described in the preceding section, the XML-based formulation comprises of ten parts. The corresponding XML-codes (including MathML parts representing mathematical expressions) are given in the Appendix. A special interface program provides transformation of the information stored in the XML-file in the form suitable for direct use of this model as input data for the CompHEP program[1] designed for matrix element calculations at the tree level.

As we mentioned above (section 2, point 4), visual representation of the model formulation in the Standard should be separated from the content. In general, this can be achieved with the help of CSS (Cascading Style Sheets) or XSL (Extensible Stylesheet Language), see, e.g. [10, 11]. However, at present (to our best knowledge) both this ways of visualization of an information stored in XML-form are incompatible with MathML. Therefore, at the moment we use for the visualization of XML-SMF the usual tags of XHTML inserted directly into the XML-files (thus violating the principle of separation of an information and its visualization). The combined XML/XHTML files can be rendered by the Mozilla browser (MathML-enabled version: Mozilla 0.9.8, see [13]). As a result, the visual representation of QED with four-fermion interactions looks as follows:

QED+4F

- *Type*: modified subset of SM

I. GENERAL PROPERTIES

Full Name: Quantum Electrodynamics with 4-fermion interactions.

Gauge Group and SUSY

Gauge Group	SUSY
$U_{EM}(1)$	No

Fundamental Interactions

Interactions	Submodel	Charge	Existence in the current model	Comments
Strong	QCD	color	no	
Electromagnetic	QED	el. charge	yes	
Weak	QFD	flavor, hypercharge	yes	low-energy effective, 4-fermion, neutral currents
Gravity	GTR	energy	no	
Nonstandard interactions			no	

Higgs Sector

Minimal SM/MSSM Higgs sector	Additional Higgs fields
No	No

Matter Sector

Number of Generations	Neutrino (existence and type)	Matter particles beyond SM/MSSM
1	No	No

Gauge Conditions

Gauge (Sub)Group	Condition	Existence of Ghosts
$U(1)$	Feynman	No

II. FIELDS ENTERING THE MODEL**Fields**

Physical Type	Lorenz Type	Symbol	Comments
electromagnetic, gauge $U(1)$, real	vector	A_μ	
matter field	Dirac spinor	ψ	
auxiliary, nondynamical, real	vector	Z_μ	

III. PARTICLES ENTERING THE MODEL

Particles

Name	Symbol	Corresponding Field	Antiparticle	Spin/Helicity	Mass
photon	γ	A_μ	γ	1	$m_\gamma = 0$
electron	e^-	ψ	e^+	1/2	m_e

IV. BASIC PHYSICAL CONSTANTS

Basic Constants

Physical meaning	Symbol
electron charge	g_e
sine of the Salam-Weinberg angle	$\sin \theta$
dimensionful parameter entering the propagator for the auxiliary Z -field	M_Z

V. DEPENDENT (AUXILIARY) PHYSICAL CONSTANTS

Auxiliary Constants

Physical meaning	Symbol	Relation to others
cosine of the Salam-Weinberg angle	$\cos \theta$	$\sqrt{1 - \sin^2 \theta}$

VI. REPRESENTATION OF MATH CONSTANTS

Math Constants

Symbol	Way of Representation
π	symbolic
$\sqrt{2}$	symbolic

VII. FREE LAGRANGIAN DENSITY

$$L_0 = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + i\bar{\psi}\gamma^\mu\partial_\mu\psi - m_e\bar{\psi}\psi - M_Z^2 Z_\mu Z^\mu$$

$$F_{\mu\nu} = \partial_\nu A_\mu - \partial_\mu A_\nu$$

VIII. GAUGE CONDITIONS (EXPLICIT FORM)

Gauge Conditions

Gauge Subgroup	Name of the Gauge Condition	Explicit Form
U_{EM}	Feynman	$\partial_\mu A^\mu = 0$

IX. PROPAGATORS

Propagators

Fields	Math Expression	Diagram Element
$\langle A_\mu A_\nu \rangle$	$-\frac{ig_{\mu\nu}}{k^2 + i\epsilon}$	$\begin{array}{c} \mu \quad k \quad \nu \\ \bullet \text{---} \text{wavy line} \text{---} \bullet \end{array}$
$\langle Z_\mu Z_\nu \rangle$	$-\frac{ig_{\mu\nu}}{M_Z^2}$	$\begin{array}{c} \mu \quad k \quad \nu \\ \bullet \text{---} \text{coiled line} \text{---} \bullet \end{array}$
$\langle \bar{\psi} \psi \rangle$	$-i \frac{\gamma_\mu k^\nu + m_e}{k^2 - m_e^2 + i\epsilon}$	$\begin{array}{c} i \quad k \quad j \\ \bullet \text{---} \text{arrow} \text{---} \bullet \end{array}$

X. INTERACTION LAGRANGIAN AND VERTICES

Propagators

Term in the Interaction Lagrangian	Factor in Matrix Elements	Diagram Element
$g_e \bar{\psi} \gamma^\mu A^\mu \psi$	$ig_e \gamma^\mu (2\pi)^4 \delta(p_1 - p_2 - k)$	$\begin{array}{c} \mu \\ \bullet \text{---} \text{wavy line} \text{---} \bullet \\ \quad \swarrow \searrow \\ \bullet \quad \bullet \end{array}$
$\frac{g_e}{4 \sin \theta \cos \theta} \bar{\psi} [\gamma^\mu (1 - \gamma_5) - 4 \sin^2 \theta \gamma^\mu] Z_\mu \psi$	$\frac{g_e}{4 \sin \theta \cos \theta} [\gamma^\mu (1 - \gamma_5) - 4 \sin^2 \theta \gamma^\mu] (2\pi)^4 \times \delta(p_1 - p_2 - k)$	$\begin{array}{c} \mu \\ \bullet \text{---} \text{coiled line} \text{---} \bullet \\ \quad \swarrow \searrow \\ \bullet \quad \bullet \end{array}$

6 Conclusion

XML provides a suitable basis for development of convenient and effective standard for QFT model formulation with possibility of exchange through Internet and reliable comparison of the results obtained by different groups and computer programs.

Of course, much work has to be done yet for realization of the whole program of development of the universal, transparent, user-friendly and widely accepted standard (XML-SMF) for QFT model formulation. Our current proposal is only a first step in this direction.

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References

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- [12] See the official Web-site on MathML <http://www.w3.org/Math>
- [13] See the Mozilla Web-site <http://www.mozilla.org/projects/mathml/build.html>

Appendix: XML-codes for Formulation of the QED with Four-Fermion Interaction

```
<?xml version="1.0" ?>

<!--          XML-standard for QFT models.
              SAMPLE: QED with 4-fermion interaction.
              Version of 14.01.2002                      -->

<!DOCTYPE html PUBLIC "-//W3C//DTD XHTML 1.0 Strict//EN" "mathml.dtd">

<MODEL name="QED+4F" type="SM" variation="subset" modification="modified">

<!-- ***** -->
<!-- **** PART I. GENERAL PROPERTIES ***** -->
<!-- ***** -->

<GEN_DESCRIPTION> Quantum Electrodynamics with 4-fermion
                    interaction.

    <GaugeGroupAndSUSY>
        <GaugeGroup> <math xmlns="http://www.w3.org/1998/Math/MathML">
            <msub><mi>U</mi><mi>EM</mi></msub>
            <mo>(</mo>
            <mn>1</mn>
            <mo>)</mo>
            </math>
        </GaugeGroup>
        <SUSY> No </SUSY>
    </GaugeGroupAndSUSY>

    <Interactions>
        <StrongQCDcolor existence="no"/>
        <ElectromagneticQEDel_charge existence="yes"/>
        <WeakQFDflavor_hypercharge existence="yes">
            low-energy effective, 4-fermion, neutral currents
        </WeakQFDflavor_hypercharge>
        <GravityGTRenergy existence="no"/>
        <NonstandardInteractions existence="no"/>
    </Interactions>

    <HiggsSector>
        <MinimalSM-MSSM existence="no"/>
        <AdditionalHiggses existence="no"/>
    </HiggsSector>
```

```

<MatterSector>
  <NumberOfGenerations Num="1"/>
  <Neutrino existenceANDtype="no"/>
  <ExtraMatter existence="no"/>
</MatterSector>

  <GaugeConditions>
    <GaugeSubgroup type="U(1)" ghosts="no"> Feynman
      </GaugeSubgroup>
    </GaugeConditions>

</GEN_DESCRIPTION>

<!-- ***** -->
<!-- **** PART II. FIELDS ENTERING THE MODEL ***** -->
<!-- ***** -->

<FIELDS>

  <FIELD LorentzType="vector" id = "A-photon"> electromagnetic,
                                                                gauge U(1), real
    <SYMBOL> <math xmlns="&mathml;">
      <mi><mrow>
        <msub>
          <mi>A</mi>
          <mi>&mu;</mi>
        </msub>
      </mrow></mi>
    </math> </SYMBOL>

  </FIELD>

  <FIELD LorentzType="Dirac spinor" id = "psi"> matter field, complex
    <SYMBOL> <math xmlns="&mathml;">
      &psi;
    </math> </SYMBOL>

  </FIELD>

  <FIELD LorentzType="vector" id = "Z-boson"> auxiliary, nondynamical, real
    <SYMBOL> <math xmlns="&mathml;">
      <mi><mrow>
        <msub>
          <mi>Z</mi>
          <mi>&mu;</mi>
        </msub>
      </mrow></mi>

```

```

</math> </SYMBOL>

</FIELD>

</FIELDS>

<!-- ***** -->
<!-- **** PART III. PARTICLES ENTERING THE MODEL ***** -->
<!-- ***** -->

<PARTICLES>

  <PARTICLE name="photon" pdgID="22">
    <SYMBOL>
      <math xmlns="&mathml;"> <mi><mrow>&gamma;</mrow></mi>
      </math> </SYMBOL>

      <CorrFIELD><math xmlns="&mathml;">
        <mi><mrow>
          <msub>
            <mi>A</mi>
            <mi>&mu;</mi>
          </msub>
          </mrow></mi>
        </math> </CorrFIELD>

      <AntiPARTICLE name="photon" pdgID="22">
        <math xmlns="&mathml;"> <mi><mrow>&gamma;</mrow></mi>
        </math> </AntiPARTICLE>

      <SPIN_or_HELICITY> 1 </SPIN_or_HELICITY>

      <MASS> <math xmlns="&mathml;">
        <mi><mrow>
          <msub>
            <mi>m</mi>
            <mi>&gamma;</mi>
          </msub>=0
          </mrow></mi>
        </math>
      </MASS>

    </PARTICLE>

  <PARTICLE name="electron" pdgID="11">
    <SYMBOL>
      <math xmlns="&mathml;"> <mi><mrow>
        <msup>

```

```

        <mi>e</mi>
    </math></SYMBOL>
</math> </SYMBOL>

<CorrFIELD><math xmlns="&mathml;">
    <mi><mrow>
        <mi>&psi;</mi>
        </mrow></mi>
    </math> </CorrFIELD>

<AntiPARTICLE name="positron" pdgID="-11">
    <math xmlns="&mathml;"> <mi><mrow>
        <msup>
            <mi>e</mi>
        </msup>
        <mo>+</mo>
    </mrow></mi>
    </math> </AntiPARTICLE>

<SPIN_or_HELICITY> 1/2 </SPIN_or_HELICITY>

<MASS> <math xmlns="&mathml;">
    <mi><mrow>
        <msub>
            <mi>m</mi>
            <mi>e</mi>
        </msub>
    </mrow></mi>
    </math>
</MASS>

</PARTICLE>

</PARTICLES>

<!-- ***** -->
<!-- **** PART IV. BASIC PHYSICAL CONSTANTS ***** -->
<!-- ***** -->

<BasicCONSTANTS>

<BCONSTANT>
    <PhysicalMeaning> electron charge </PhysicalMeaning>
    <SYMBOL> <math xmlns="&mathml;">
        <mi><mrow>
            <msub>
                <mi>g</mi>
                <mi>e</mi>
            </msub>
        </mrow></mi>
    </math>
    </SYMBOL>
    </BCONSTANT>
</BasicCONSTANTS>

```

```

        </msub>
        </mrow></mi>
    </math>        </SYMBOL>
</BCONSTANT>

<BCONSTANT>
    <PhysicalMeaning> sine of the Salam-Weinberg angle </PhysicalMeaning>
    <SYMBOL> <math xmlns="&mathml;">
        <mrow><mi>sin</mi><mi>&theta;</mi>
        </mrow>
    </math>        </SYMBOL>
</BCONSTANT>

<BCONSTANT>
    <PhysicalMeaning> dimensionful parameter entering the propagator
        for the auxiliary Z-field        </PhysicalMeaning>
    <SYMBOL> <math xmlns="&mathml;">
        <mi><mrow>
            <msub>
                <mi>M</mi>
                <mi>Z</mi>
            </msub>
        </mrow></mi>
    </math>        </SYMBOL>
</BCONSTANT>

</BasicCONSTANTS>

<!-- ***** -->
<!-- **** PART V. DEPENDENT (AUXILIARY) PHYSICAL CONSTANTS ***** -->
<!-- ***** -->

<AuxCONSTANTS>

    <ACONSTANT>
        <PhysicalMeaning> cosine of the Salam-Weinberg angle </PhysicalMeaning>
        <SYMBOL> <math xmlns="&mathml;">
            <mi><mrow>
                <mi>cos</mi>
                <mi>&theta;</mi>
            </mrow></mi>
        </math>        </SYMBOL>
        <RELATION_TO_OTHERS> <math xmlns="&mathml;">
            <msqrt>
                <mrow>
                    <mn>1</mn>
                    <mo>-</mo>
                </mrow>
            </msqrt>

```



```

        <mi>sin</mi><mn>2</mn>
        </msup>
        <mi>&theta;</mi>
    </mrow></msqrt>
</math>          </RELATION_TO_OTHERS>
</ACONSTANT>

</AuxCONSTANTS>

<!-- ***** -->
<!-- **** PART VI. REPRESENTATIN OF MATH CONSTANTS ***** -->
<!-- ***** -->

<MathCONSTANTS>

    <MCONSTANT>
        <SYMBOL> <math xmlns="&mathml;">
            <mrow> <msqrt><mn>2</mn></msqrt></mrow>
            </math>          </SYMBOL>
        <CompRepresentation> symbolic </CompRepresentation>
    </MCONSTANT>

    <MCONSTANT>
        <SYMBOL> <math xmlns="&mathml;">
            <mrow><mi>&pi;</mi></mrow>
            </math>          </SYMBOL>
        <CompRepresentation> symbolic </CompRepresentation>
    </MCONSTANT>

</MathCONSTANTS>

<!-- ***** -->
<!-- **** PART VII. FREE LAGRANGIAN DENSITY ***** -->
<!-- ***** -->

<FreeLagrangian higgs_shift = " ">

    <!-- the parameter higgs_shift may have values "before Higgs field
    shift", "after Higgs field shift" or blank_space -->

    <math xmlns="&mathml;">
        <mrow> <msub><mi>L</mi><mn>0</mn></msub>
        <mo>=</mo>
        <mo>-</mo>
        <mi></mi>
        <mfrac><mn>1</mn><mn>4</mn></mfrac>
        <msub><mi>F</mi><mi>&mu;&nu;</mi></msub>

```

```

<msup><mi>F</mi><mi>&mu;&nu;</mi></msup>
<mo> + </mo>
<mi>i</mi> <mover><mi>&psi;</mi><mo>&OverBar;</mo></mover>
<msup><mi>&gamma;</mi><mi>&mu;</mi></msup>
<msub><mo>&PartialD;</mo><mi>&mu;</mi></msub><mi>&psi;</mi>
<mo>-</mo>
<msub><mi>m</mi><mi>e</mi></msub>
<mover><mi>&psi;</mi><mo>&OverBar;</mo></mover><mi>&psi;</mi>
<mo>-</mo>
<msubsup><mi>M</mi><mi>Z</mi><mn>2</mn></msubsup>
<msup><mi>Z</mi><mi>&mu;</mi></msup>
<msub><mi>Z</mi><mi>&mu;</mi></msub>
</mrow>
</math>

```

```

<math xmlns="&mathml;">
  <mrow>
    <msub><mi>F</mi><mi>&mu;&nu;</mi></msub>
    <mo>=</mo>
    <msub><mo>&PartialD;</mo><mi>&nu;</mi></msub>
    <msub><mi>A</mi><mi>&mu;</mi></msub>
    <mo>-</mo>
    <msub><mo>&PartialD;</mo><mi>&mu;</mi></msub>
    <msub><mi>A</mi><mi>&nu;</mi></msub>
  </mrow>
</math>

```

</FreeLagrangian>

```

<!-- ***** -->
<!-- **** PART VIII. GAUGE CONDITIONS (EXPLICIT EXPR) *** -->
<!-- ***** -->

```

<GaugeConditionsExplicitExpr>

<GaugeSubgroup>

```

<math xmlns="&mathml;">
  <msub><mi>U</mi><mi>EM</mi></msub>
  <mo>(</mo>
  <mn>1</mn>
  <mo>)</mo>
</math>

```

<GaugeCondition name = "Feynman">

```

<math xmlns="&mathml;">
  <mrow>
    <msub><mo>&PartialD;</mo><mi>&mu;</mi></msub>
    <msup><mi>A</mi><mi>&mu;</mi></msup>
  </mrow>

```

```

        <mo>=</mo><mn>0</mn>
      </mrow>
    </math>

    </GaugeCondition>

  </GaugeSubgroup>
</GaugeConditionsExplicitExpr>

<!-- ***** -->
<!-- **** PART IX. PROPAGATORS ***** -->
<!-- ***** -->

<PROPOGATORS>

  <PROPOGATOR FieldRef1 ="A-photon" vectIndex1 = "mu"
    FieldRef2 ="A-photon" vectIndex2 = "nu" img="phot_prp.gif">
    <fields> <math xmlns="&mathml;"> <msub><mrow>
      <mi>&#60;</mi>
      <mrow>
        <msub>
          <mi>A</mi>
          <mi>&mu;</mi>
        </msub>
      </mrow>
      <mrow>
        <msub>
          <mi>A</mi>
          <mi>&nu;</mi>
        </msub>
      </mrow><mi>&#62;</mi></mrow><mn>0</mn></msub>
    </math>
    </fields>
    <expression>
    <math xmlns="&mathml;">
      <mrow><mo>-</mo>
        <mfrac><mrow><mi>i</mi><msub><mi>g</mi>
          <mi>&mu;&nu;</mi></msub></mrow>
          <mrow><msup><mi>k</mi><mn>2</mn></msup>
          <mo>+</mo><mi>i</mi><mi>&epsilon;</mi></mrow>
        </mfrac>
      </mrow>
    </math>
    </expression>
  </PROPOGATOR>

  <PROPOGATOR FieldRef1 ="psi" spinIndex1 = "i"
    FieldRef2 ="psi" spinIndex2 = "j" img="el_prp.gif">

```

```

<fields> <math xmlns="&mathml;"> <msub><mrow>
    <mi>&#60;</mi>
    <mrow>
        <mi>&psi;</mi>
        <mi>&psi;</mi>
    </mrow>
    <mi>&#62;</mi></mrow><mn>0</mn></msub>
</math>
</fields>
<expression>
    <math xmlns="&mathml;">
        <mrow><mi>i</mi>
        <mfrac><mrow><msub><mi>&gamma;</mi><mi>&mu;</mi></msub>
            <msup> <mi>k</mi><mi>&mu;</mi></msup>
            <mo>+</mo><msub><mi>m</mi><mi>e</mi></msub></mrow>
            <mrow><msup><mi>k</mi><mn>2</mn></msup>
            <mo>-</mo><msubsup><mi>m</mi><mi>e</mi><mn>2</mn></msubsup>
            <mo>+</mo><mi>i</mi><mi>&epsilon;</mi></mrow>
        </mfrac>
    </mrow>
    </math>
</expression>
</PROPOGATOR>

<PROPOGATOR FieldRef1 ="Z-boson" vectIndex1 = "mu"
    FieldRef2 ="Z-boson" vectIndex2 = "nu" img="z_prp.gif">
<fields> <math xmlns="&mathml;"> <msub><mrow>
    <mi>&#60;</mi>
    <mrow>
        <msub>
            <mi>Z</mi>
            <mi>&mu;</mi>
        </msub>
    </mrow>
    <mrow>
        <msub>
            <mi>Z</mi>
            <mi>&nu;</mi>
        </msub>
    </mrow><mi>&#62;</mi></mrow><mn>0</mn></msub>
</math>
</fields>
<expression>
<math xmlns="&mathml;">
    <mrow><mo>-</mo>
    <mfrac><mrow><mi>i</mi><msub><mi>g</mi>
        <mi>&mu;&nu;</mi></msub></mrow>
        <mrow><msubsup><mi>M</mi><mi>Z</mi><mn>2</mn></msubsup>

```

```

                </mrow>
            </mfrac>
        </mrow>
    </math>
</expression>
</PROPOGATOR>

</PROPOGATORS>

<!-- ***** -->
<!-- **** PART X. INTERACTION LAGRANGIAN AND VERTICES **** -->
<!-- ***** -->

<VERTICES>

    <VERTEX vertexID="eep" img="eep.gif">

        <TERMinINTERACTION_LAGRANGIAN>
        <math xmlns="&mathml;">
            <mrow><msub><mi>g</mi><mi>e</mi></msub>
                <mover><mi>&psi;</mi><mo>&OverBar;</mo></mover>
            <msup><mi>&gamma;</mi><mi>&mu;</mi></msup>
            <msub><mi>A</mi><mi>&mu;</mi></msub><mi>&psi;</mi>
            </mrow>
        </math>
        </TERMinINTERACTION_LAGRANGIAN>

        <FACTORinMATRIX_ELEMENTS>
        <math xmlns="&mathml;">
            <mrow>
                <mi>i</mi><msub><mi>g</mi><mi>e</mi></msub>
                <msup><mi>&gamma;</mi><mi>&mu;</mi></msup>
                <msup><mrow><mo>(</mo><mn>2</mn><mi>&pi;</mi><mo>)</mo></mrow>
                <mn>4</mn></msup>
                <mi>&delta;</mi><mo>(</mo><msub><mi>p</mi><mi>1</mi></msub>
                <mo>-</mo><msub><mi>p</mi><mi>2</mi></msub>
                <mo>-</mo><mi>k</mi><mo>)</mo>
            </mrow>
        </math>
        </FACTORinMATRIX_ELEMENTS>
    </VERTEX>

    <VERTEX vertexID="eez" img="eez.gif">>

        <TERMinINTERACTION_LAGRANGIAN>
            <math xmlns="&mathml;">
                <mrow>
                    <mfrac><msub><mi>g</mi><mi>e</mi></msub>

```

```

<mrow><mn>4</mn><mrow><mi>sin</mi><mi>&theta;</mi></mrow>
      <mrow><mi>cos</mi><mi>&theta;</mi></mrow></mrow></mfrac>
      <mover><mi>&psi;</mi><mo>&OverBar;</mo></mover>
    <mo>[</mo>
      <msup><mi>&gamma;</mi><mi>&mu;</mi></msup>
      <mo>(</mo><mn>1</mn><mo>-</mo>
      <msub><mi>&gamma;</mi><mi>5</mi></msub><mo>)</mo>
      <mo>-</mo><mn>4</mn>
      <msup><mi>sin</mi><mi>2</mi></msup><mi>&theta;</mi>
      <msup><mi>&gamma;</mi><mi>&mu;</mi></msup>
      <mo>]</mo>
      <msub><mi>Z</mi><mi>&mu;</mi></msub><mi>&psi;</mi>
    </mrow>
  </math>
</TERMinINTERACTION_LAGRANGIAN>

<FACTORinMATRIX_ELEMENTS>
  <math xmlns="&mathml;">
    <mrow>
      <mi>i</mi>
      <mfrac><msub><mi>g</mi><mi>e</mi></msub>
<mrow><mn>4</mn><mrow><mi>sin</mi><mi>&theta;</mi></mrow></mrow>
      <mrow><mi>cos</mi><mi>&theta;</mi></mrow></mrow></mfrac>
      <mo>[</mo>
      <msup><mi>&gamma;</mi><mi>&mu;</mi></msup>
      <mo>(</mo><mn>1</mn><mo>-</mo>
      <msub><mi>&gamma;</mi><mi>5</mi></msub><mo>)</mo>
      <mo>-</mo><mn>4</mn>
      <msup><mi>sin</mi><mi>2</mi></msup><mi>&theta;</mi>
      <msup><mi>&gamma;</mi><mi>&mu;</mi></msup>
      <mo>]</mo>
      <msup><mrow><mo>(</mo><mn>2</mn><mi>&pi;</mi><mo>)</mo></mrow>
      <mn>4</mn></msup>
      <mi>&delta;</mi><mo>(</mo><msub><mi>p</mi><mi>1</mi></msub>
      <mo>-</mo><msub><mi>p</mi><mi>2</mi></msub>
      <mo>-</mo><mi>k</mi><mo>)</mo>
    </mrow>
  </math>
</FACTORinMATRIX_ELEMENTS>
</VERTEX>
</VERTICES>
<!-- ***** -->
<!-- ***** -->
</MODEL>

```